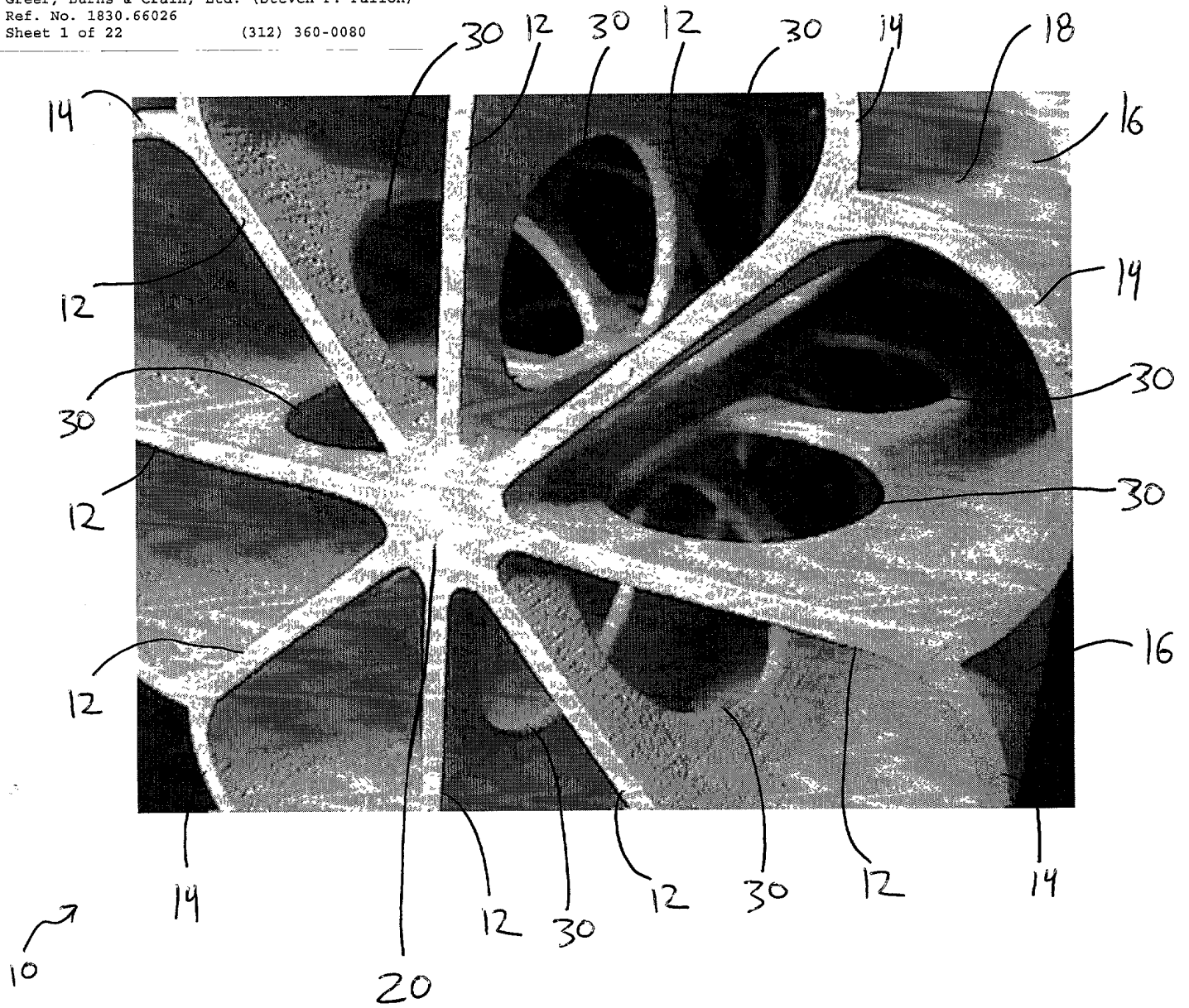


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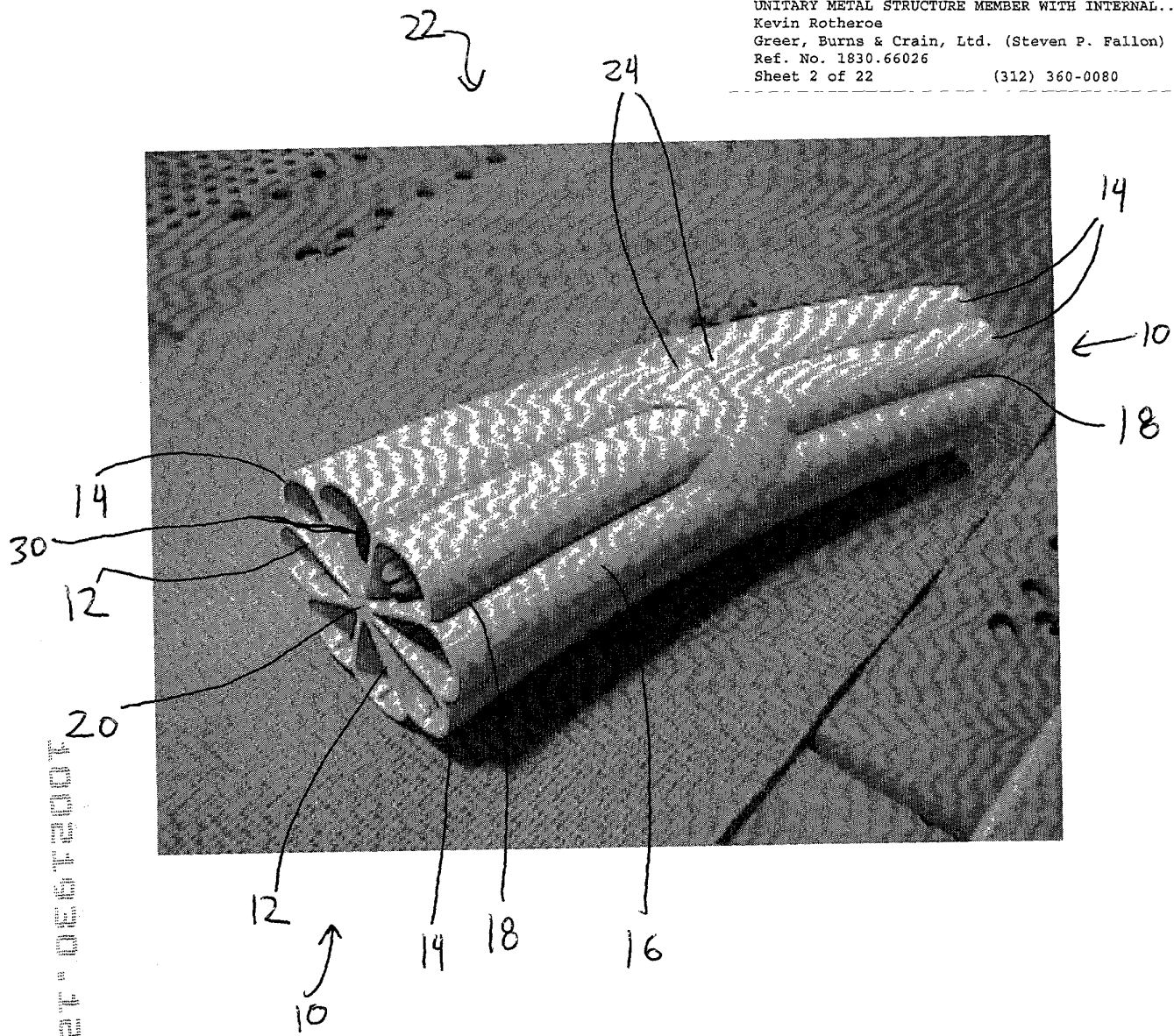


FIG. 2

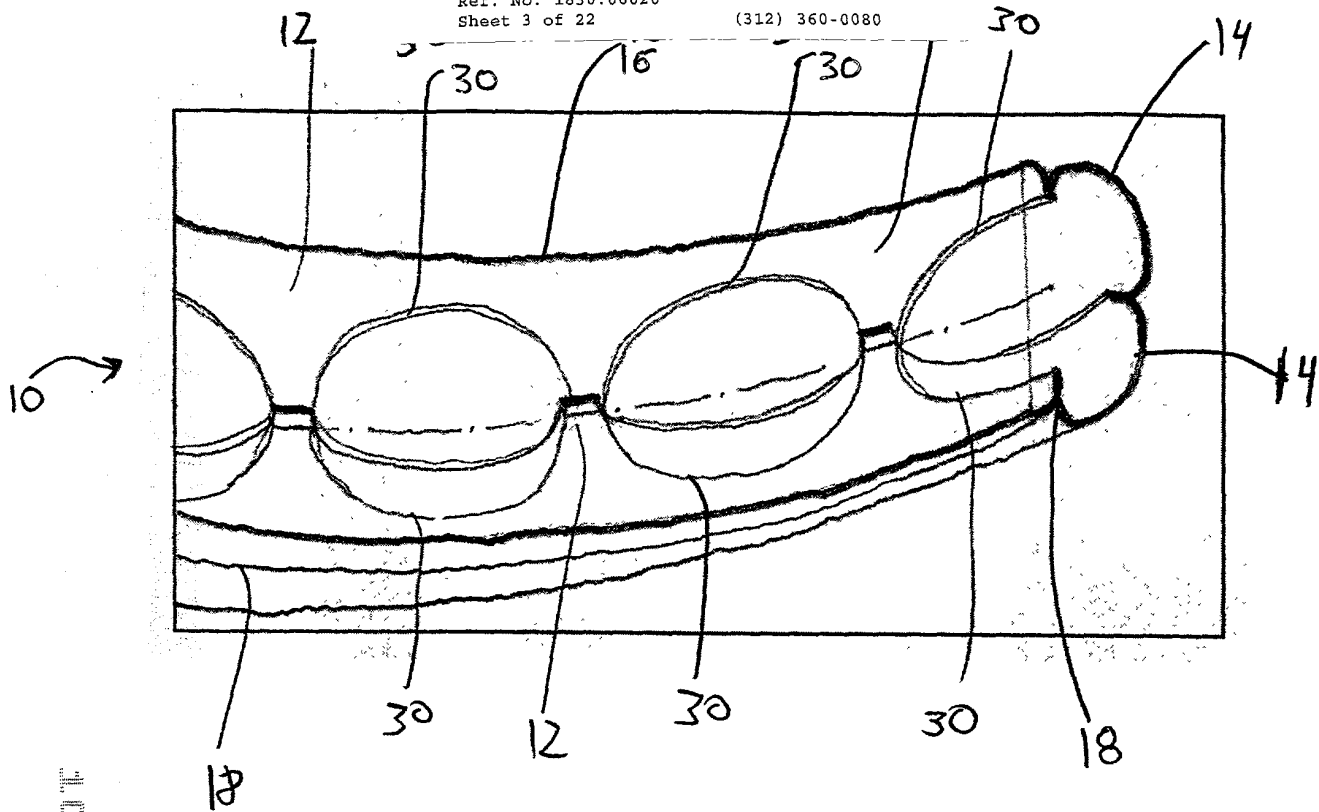


FIG. 3

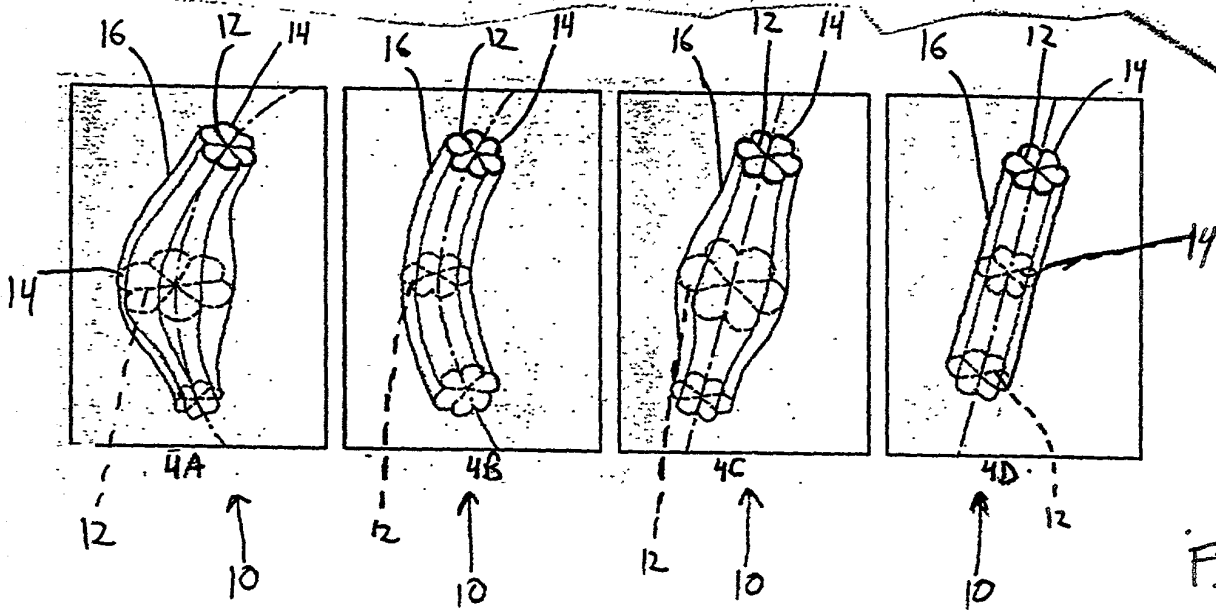
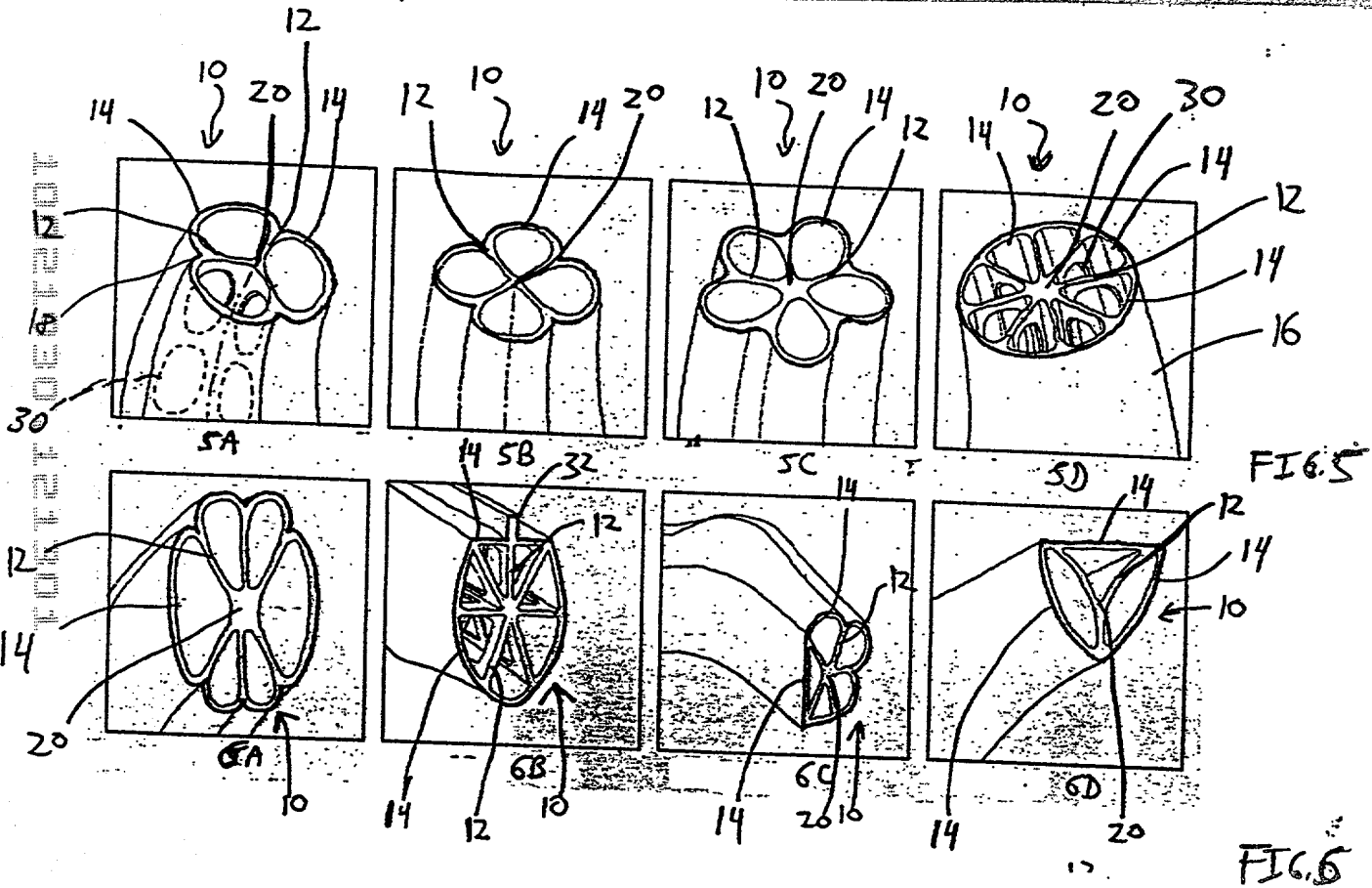


FIG. 4



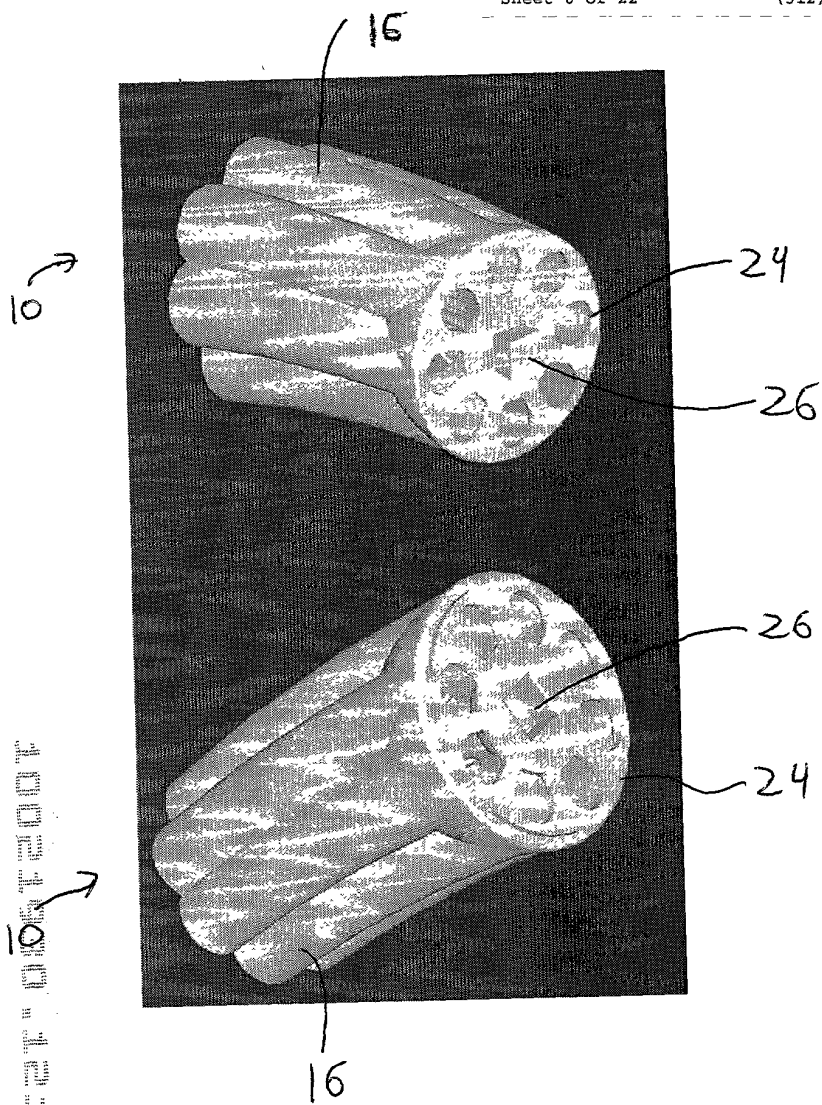
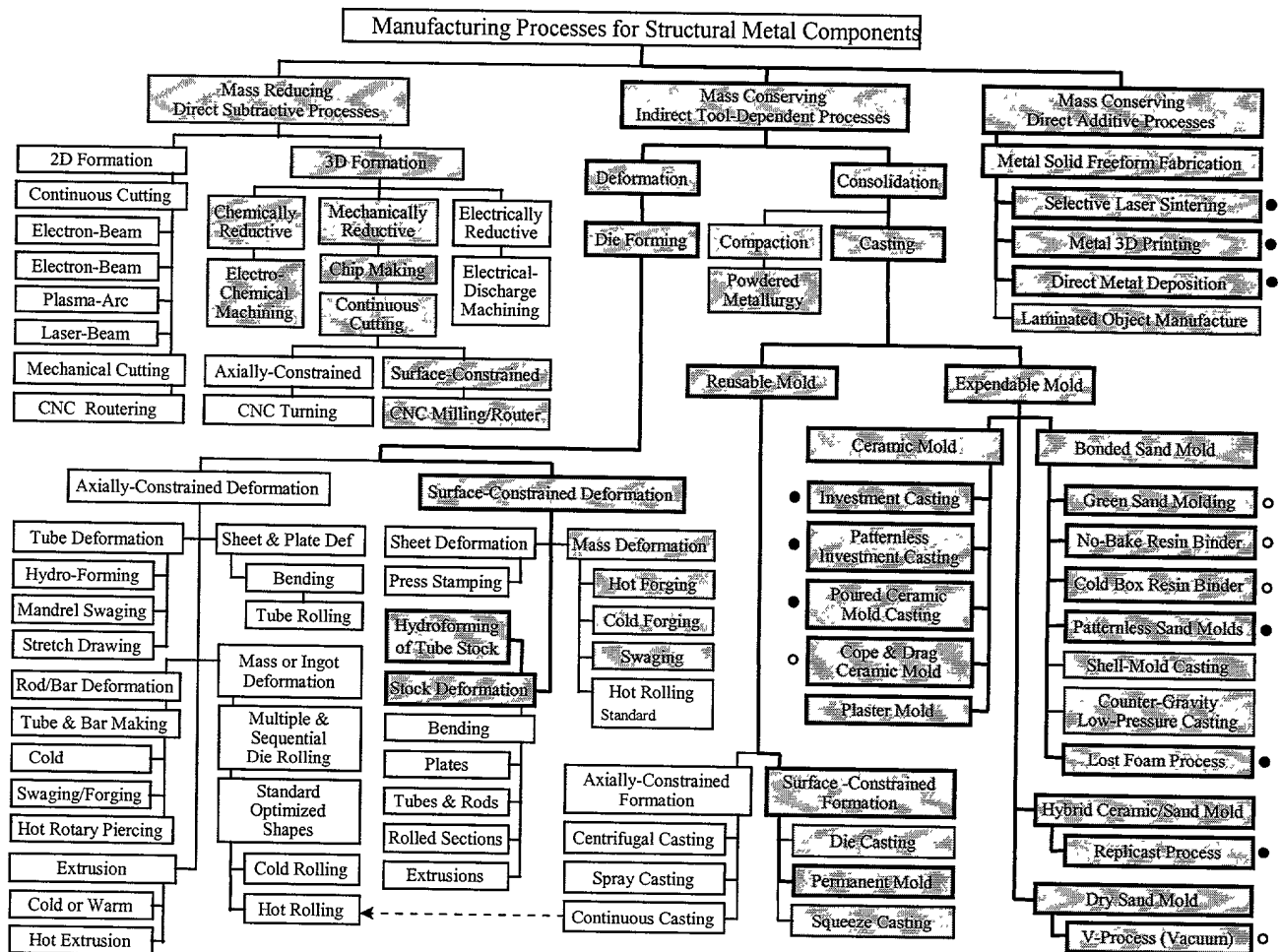


FIG. 8



- Process with Capacity to Produce Complexly-Shaped Solid Components.
- Process with Capacity to Produce Complexly-Shaped Tubular as well as Solid Components.
- Process with Capacity to Produce Complexly-Shaped Tubes with Very Limited Internal Features.
- Process with Capacity to Produce Complexly-Shaped Tubes with Extensive Internal Features.
- Process with No Capacity to Produce Complexly-Shaped Solid or Tubular Components.

Tooling Classification						Process Status	Fundamental Computer-Aided Manufacturing Processes for Complexly-Shaped Metal Structural Components:	Capacity to Produce Freeform Components: ■ Capacity □ Limited Capacity	Complexly-Shaped Solids	Freeform Tubes	Tubes w/Internal Features
Hard Die	Hard Mold	Soft Mold	Expendable Mold	Hard Pattern	Expendable Pattern						
						Established	Direct Production Processes:				
						Established	1 3D Data → Additive Formation → Component				
						Established	2 3D Data → Subtractive Formation → Component				
						Emerging	Direct Expendable Mold Processes (Direct Tooling):				
						Emerging	3 3D Data → Additive Formation → Expendable Mold → Component				
						Emerging	4 3D Data → Subtractive Formation → Expendable Mold → Component				
						Established	Indirect Expendable Mold Processes:				
						Established	5 3D Data → Additive Formation → Expendable Pattern → Expendable Mold → Component				
						Established	6 3D Data → Subtractive Formation → Expendable Pattern → Expendable Mold → Component				
						Established	7 3D Data → Subtractive Formation → Permanent Mold → Expendable Pattern → Expendable Mold → Component				
						Established	8 3D Data → Additive Formation → Net Shape Mold → Subtractive Formation → Permanent Mold → Expendable Pattern → Expendable Mold → Component				
						Established	9 3D Data → Additive Formation → Master Pattern → Expendable Mold → Component				
						Established	10 3D Data → Subtractive Formation → Master Pattern → Expendable Mold → Component				
						Established	11 3D Data → Additive Formation → Master Pattern → Short-Life Mold → Expendable Pattern → Expendable Mold → Component				
						Established	12 3D Data → Subtractive Formation → Master Pattern → Short-Life Mold → Expendable Pattern → Expendable Mold → Component				
						Established	Direct Permanent Mold Production Processes:				
						Established	13 3D Data → Additive Formation → Permanent Mold → Component				
						Established	14 3D Data → Additive Formation → Net Shape Mold → Subtractive Formation → Permanent Mold → Component				
						Established	15 3D Data → Subtractive Formation → Permanent Mold → Component				
						Established	Direct Permanent Die Production Processes:				
						Established	16 3D Data → Additive Formation → Permanent Die Set → Component				
						Established	17 3D Data → Additive Formation → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component				
						Established	18 3D Data → Subtractive Formation → Permanent Die Set → Component				
						Established	Indirect Permanent Die Production Processes:				
						Established	19 3D Data → Additive Formation → Expendable Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component				
						Established	20 3D Data → Subtractive Formation → Expendable Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component				
						Established	21 3D Data → Subtractive Formation → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component				
						Established	22 3D Data → Additive Formation → Master Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component				
						Established	23 3D Data → Subtractive Formation → Master Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component				

Note: Permanent mold processes have the capacity to produce freeform metal tubes if sand cores are used, which is an established method. As with other pattern & mold-based processes, the capacity to produce internal features is limited by pattern or product removal.

FIG. 9

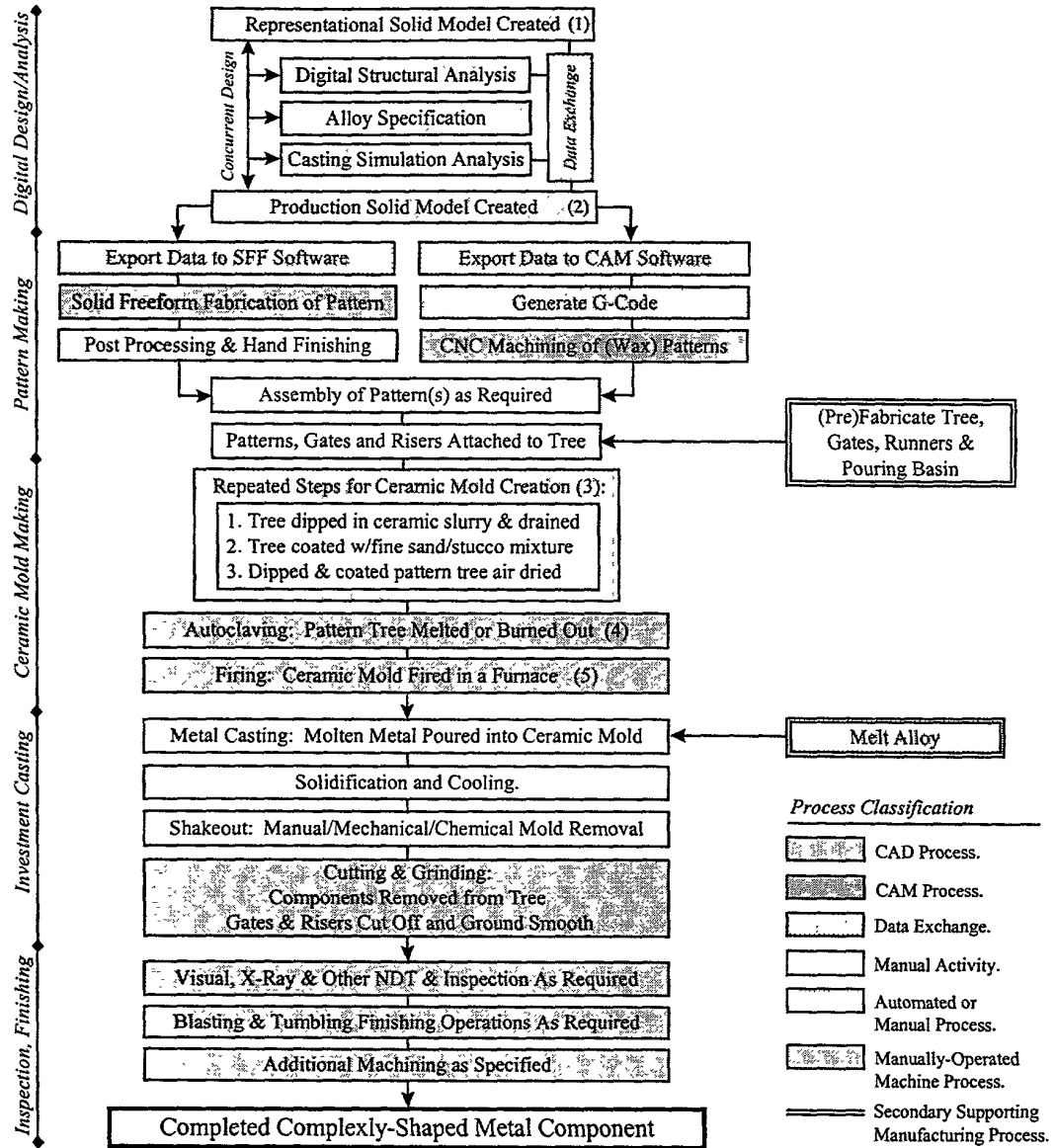
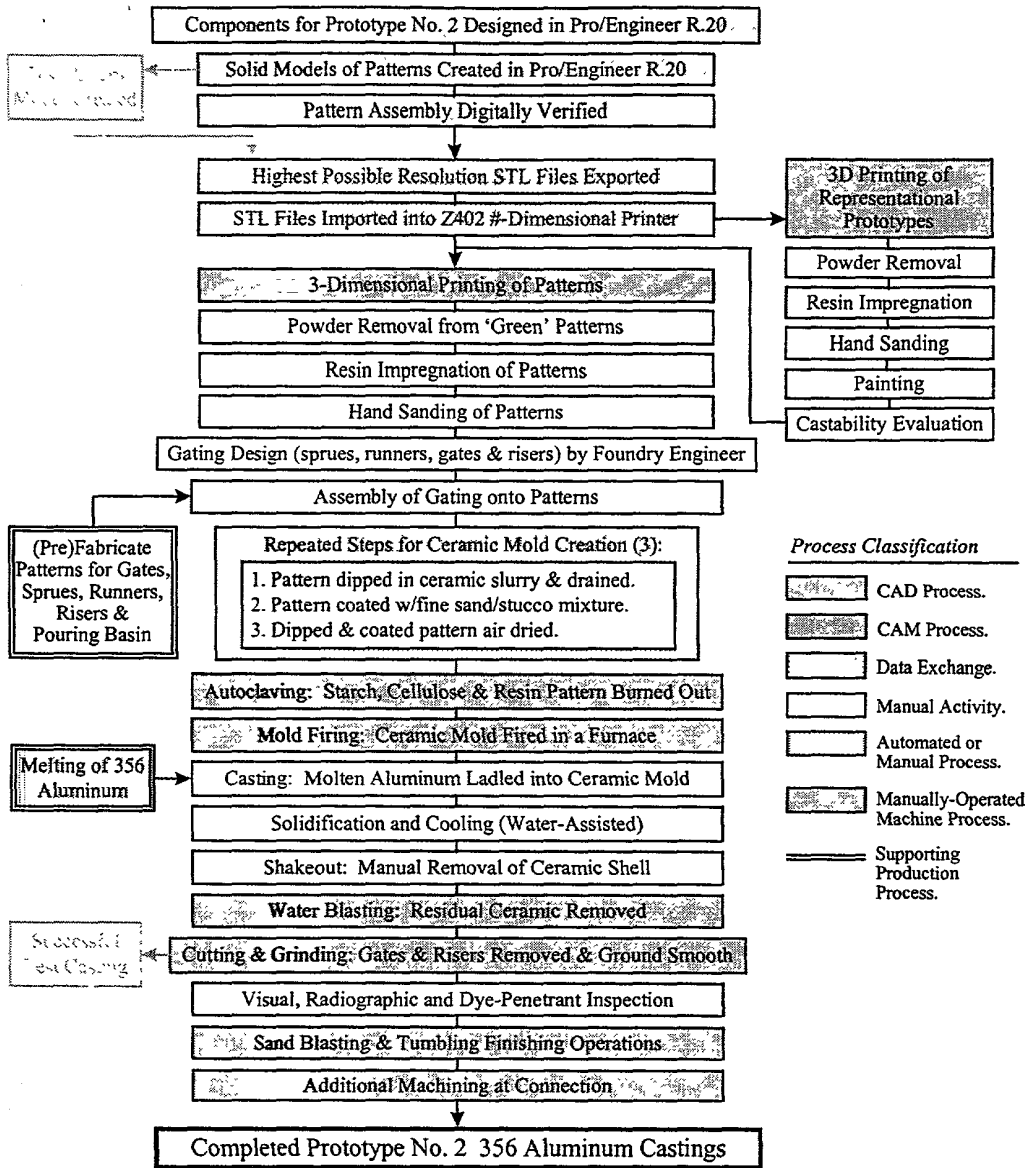


FIG 10

Finish & Inspect Post-Processing Casting Ceramic Mold Making Pattern Making Data Transfer Digital Design



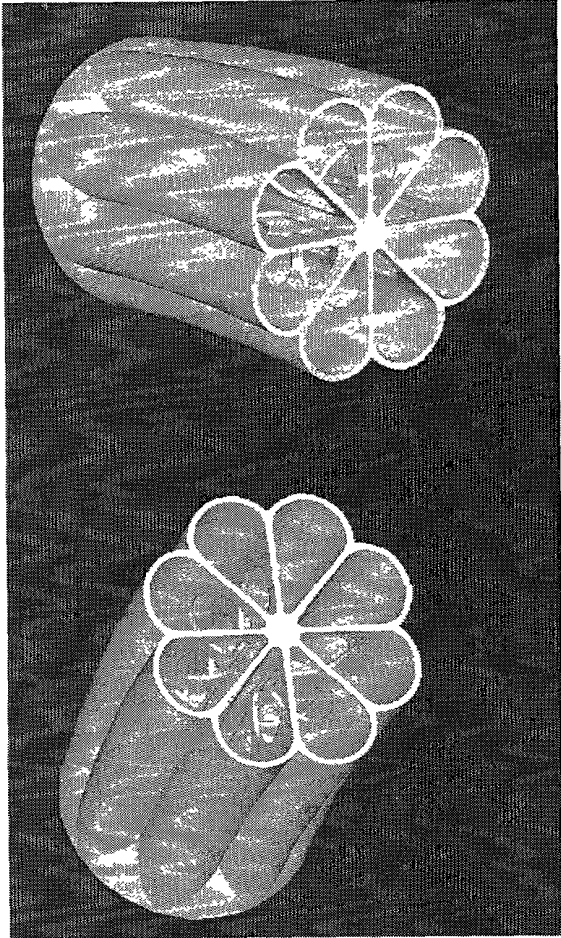


FIG. 12

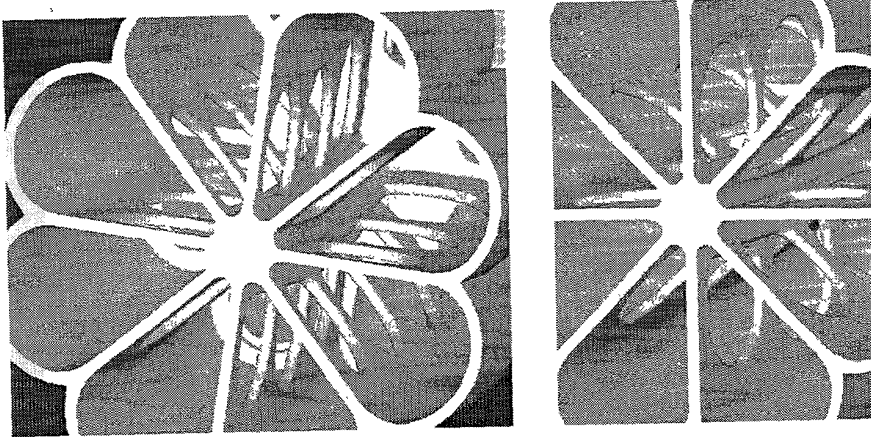


FIG. 13

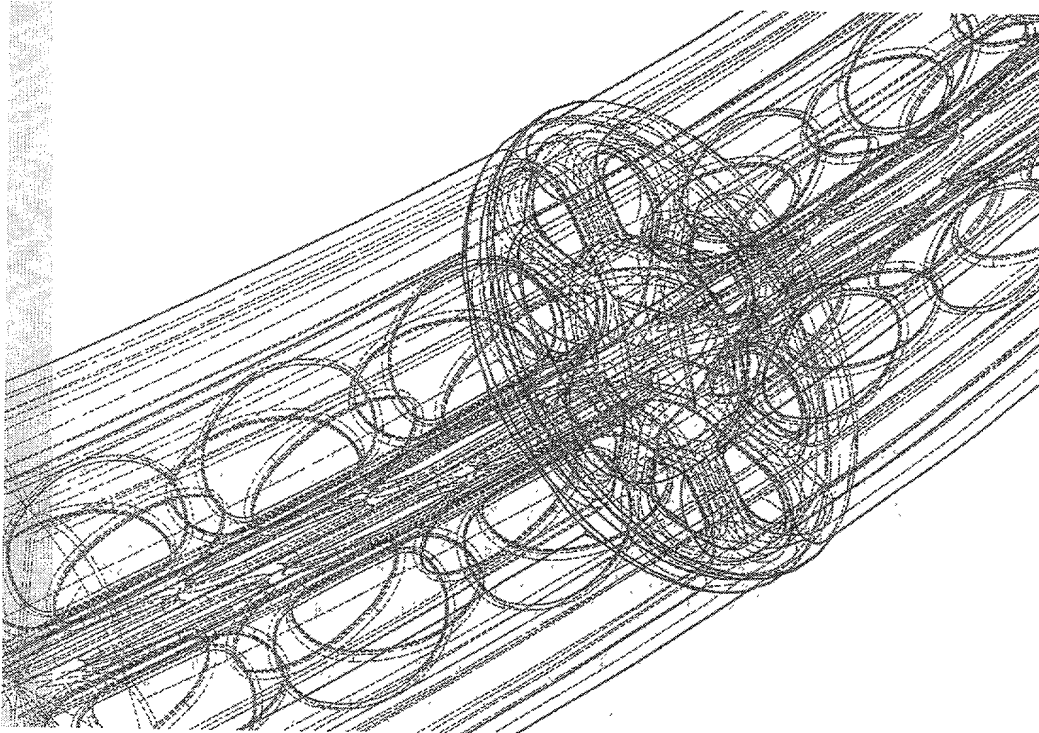
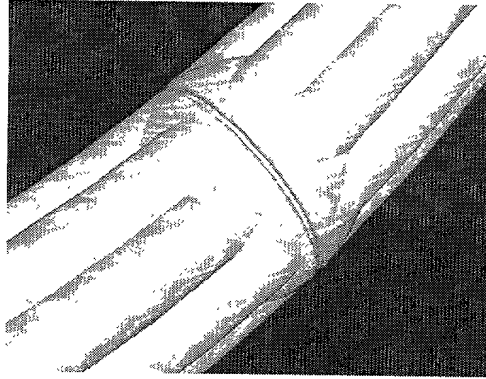
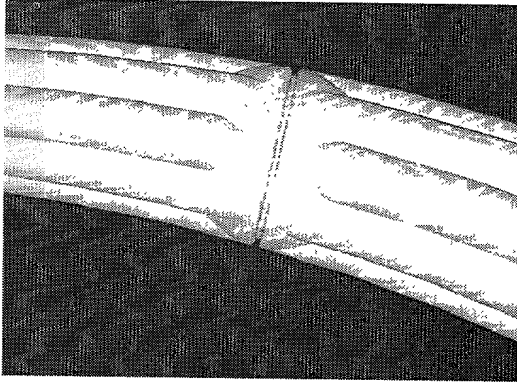


FIG. 14

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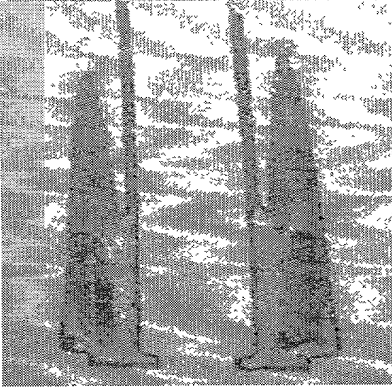
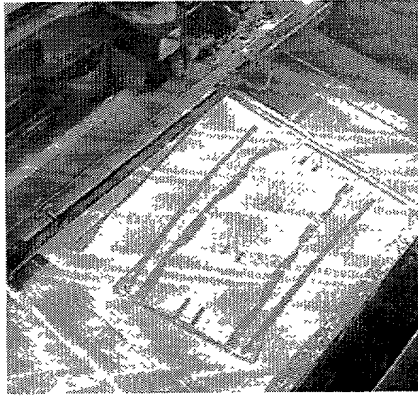
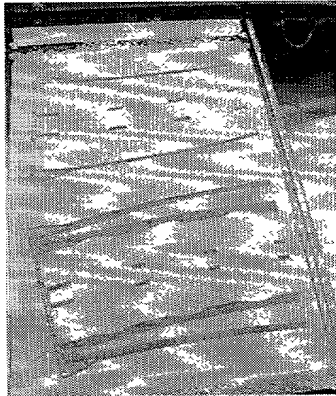


FIG 15

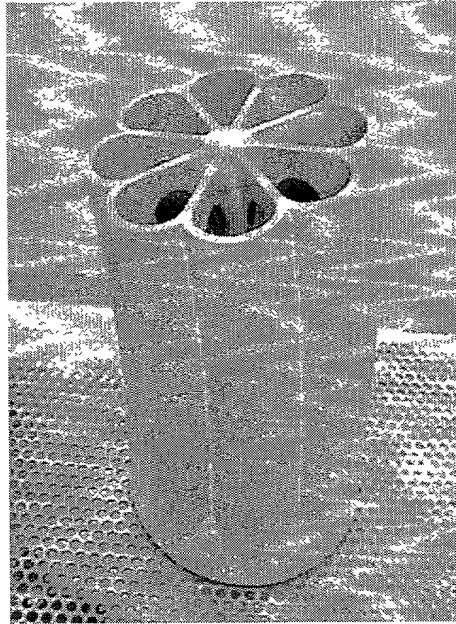
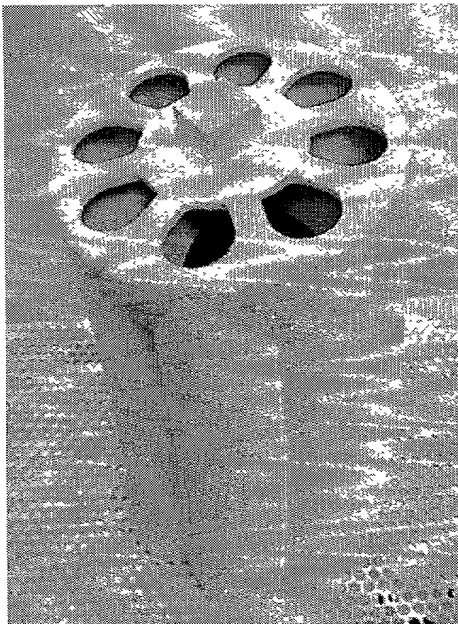


FIG. 16

FIG. 15

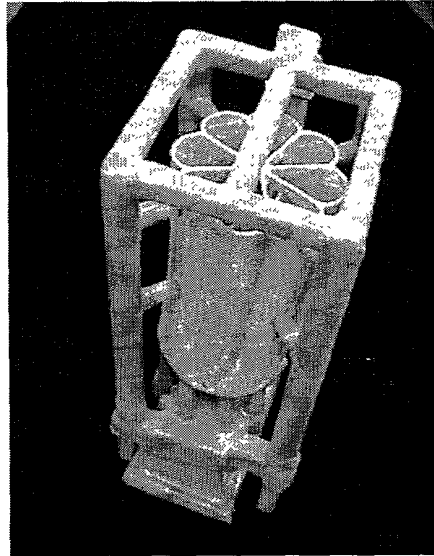
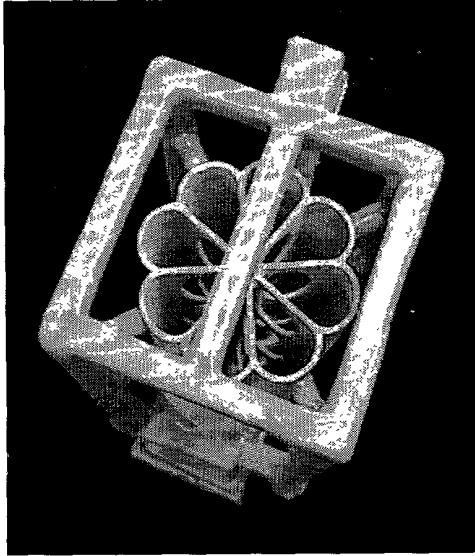


FIG. 17

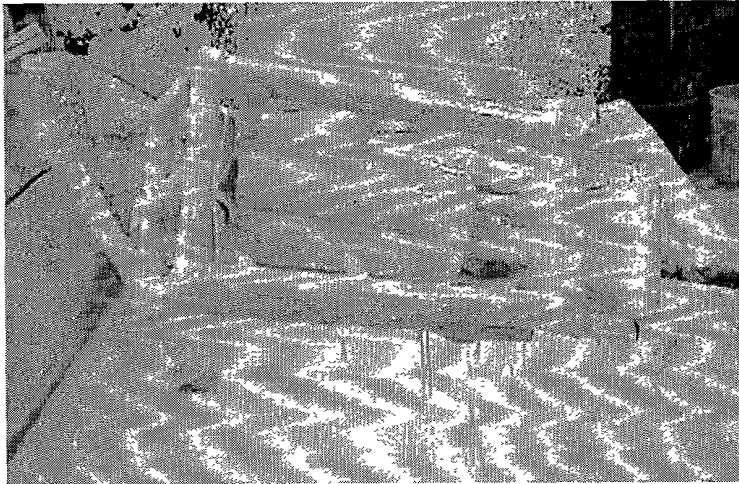


FIG. 18

1830.66026



FIG. 19

10024930 10024930 10024930

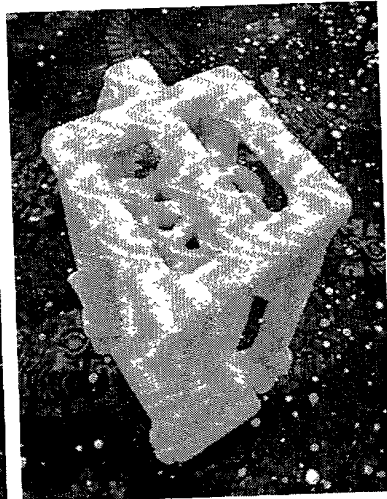
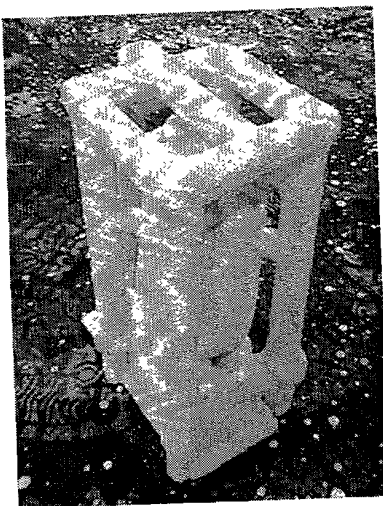
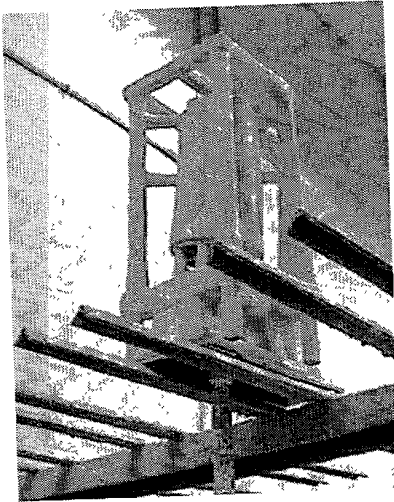


FIG. 20

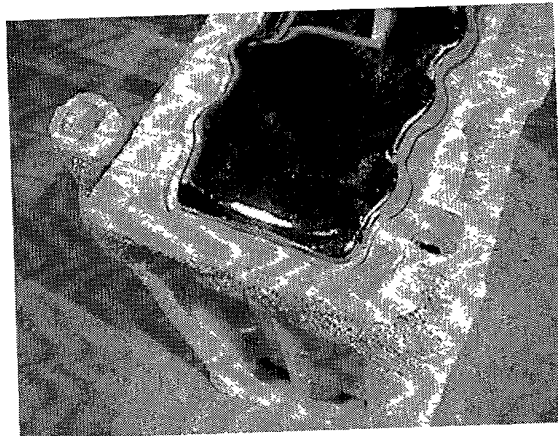
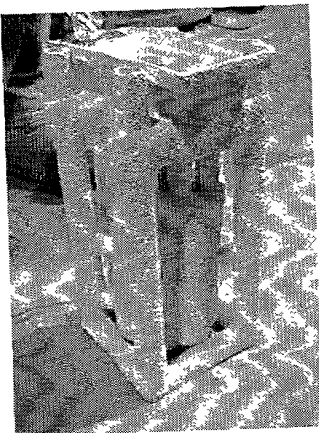


FIG. 21

FIG. 20

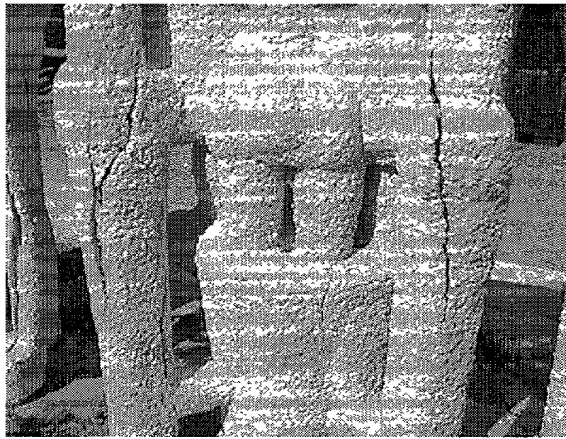
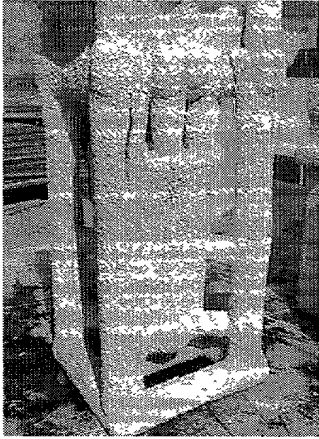


FIG. 22

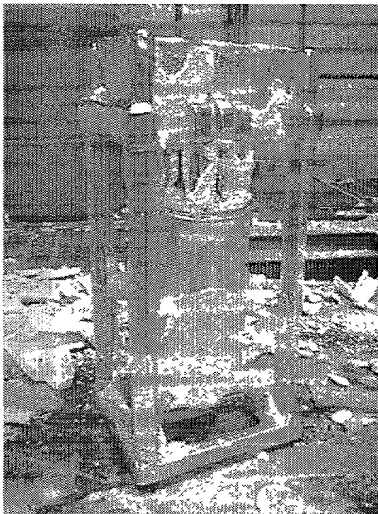


FIG. 23

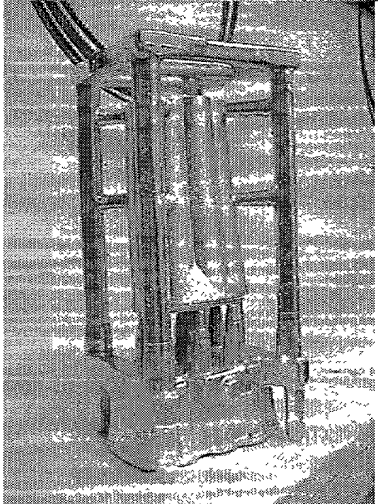


FIG. 24

FIG. 21

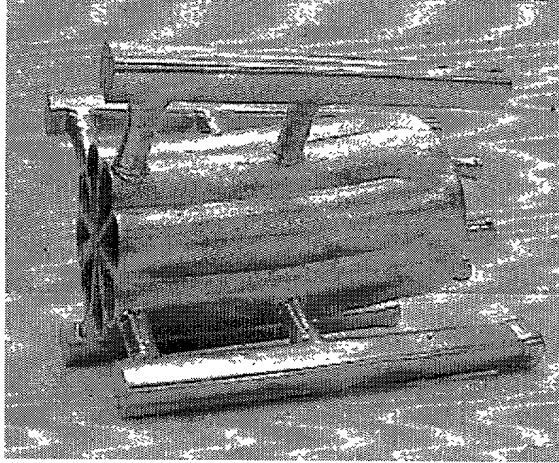
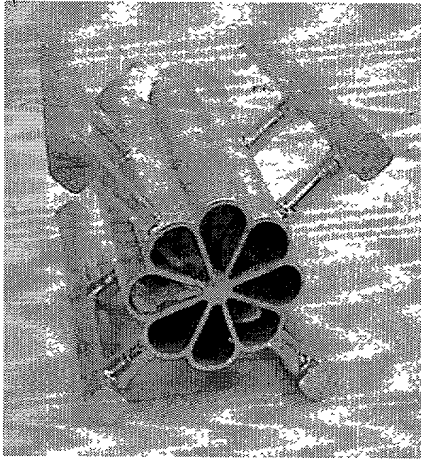


FIG. 25

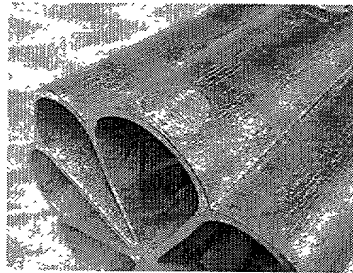
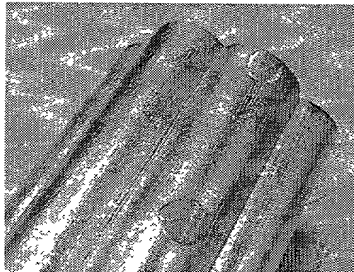
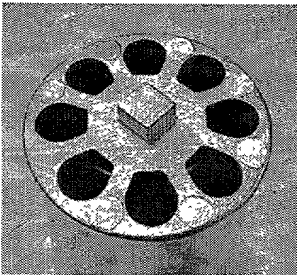


FIG 26

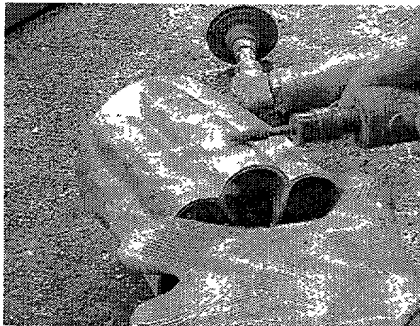
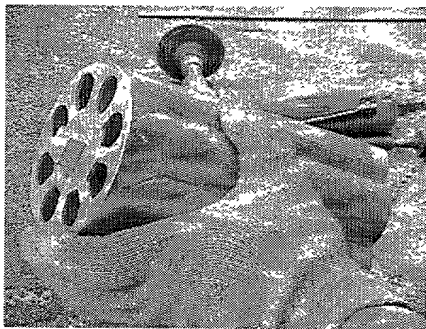


FIG. 27

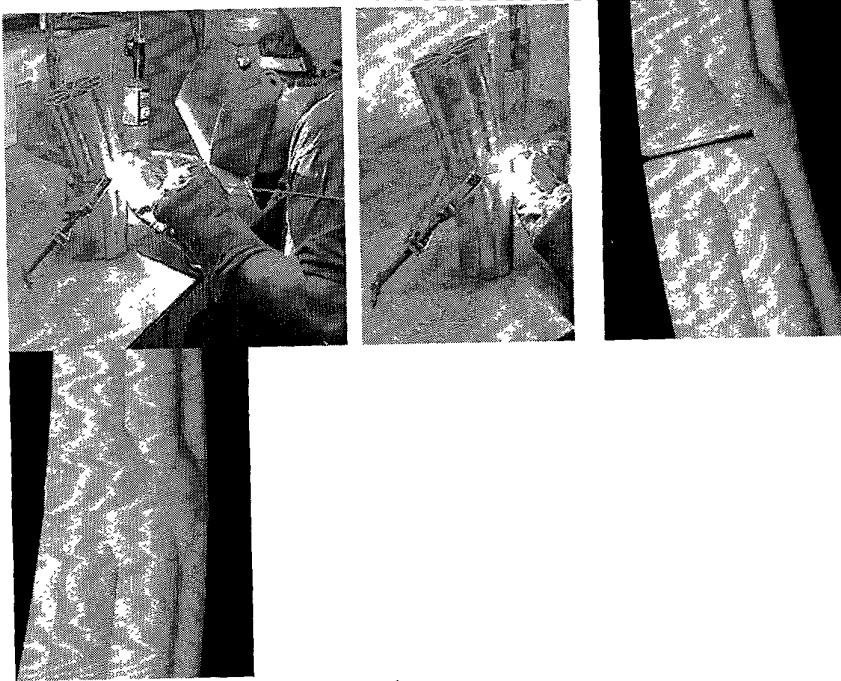


FIG. 28

FIG. 29

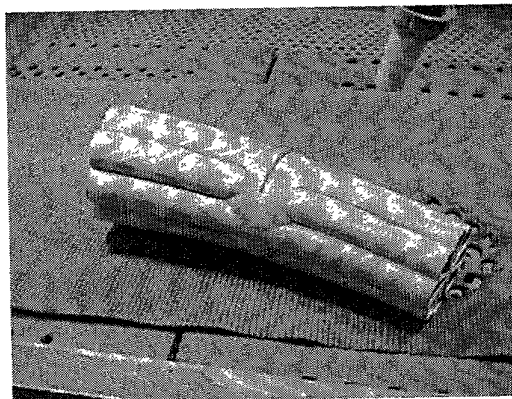
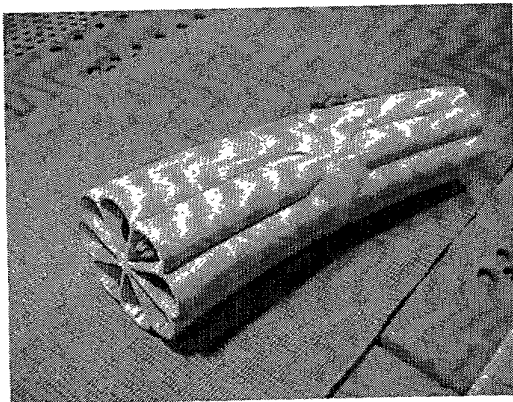


FIG. 30

UNITARY METAL STRUCTURE MEMBER WITH INTERNAL...



31A



31B

FIG. 31

10001930 121301

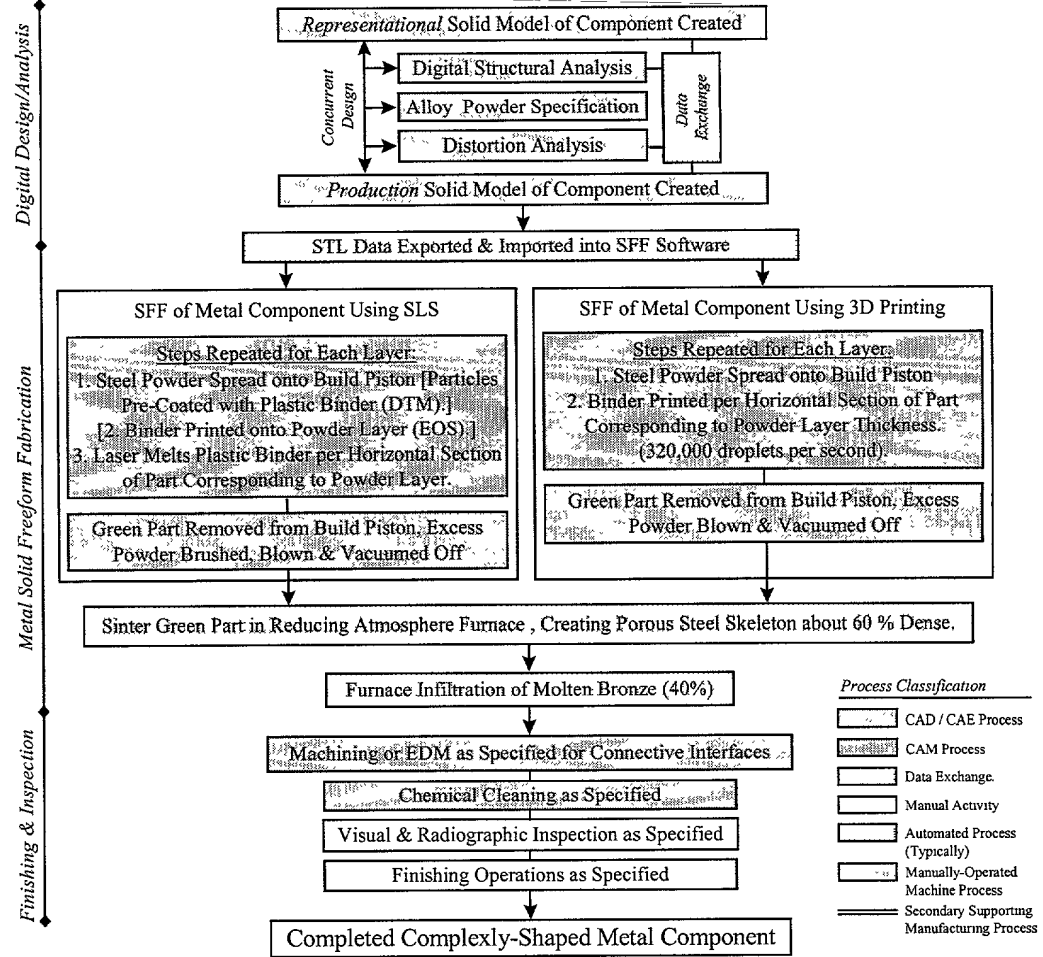


FIG. 32